Science on Soil Carbon

Marshall McDaniel
Assistant Professor in Soil-Plant Interactions | Agronomy | ISU
Carbon Market Webinar | 11 August 2021

Science on Soil Carbon

1. **Soil C and Markets**
   - Carbon craze
   - Terminology & Background
2. **Known Knowns**
   - Conservation practices increase SOC
3. **Known Unknowns**
   - Monitoring SOC change is challenging
   - Co-benefits/tradeoffs with increasing SOC
4. **Unknown Unknowns**
   - Government involvement
   - Best way to monitor/verify SOC
5. **Conclusion**

[Do we know enough to move ahead on C Markets?]

McDaniel Lab
Soil-Plant IXNs

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@Soil_Plant_IXNS on Twitter

Emerging C Markets!

DJIA 30401.93 0.01% ▼ S&P 500 3740.80 0.15% ▲ Nasdaq 12881.77 0.14% ▼ U.S. 10 Yr -1/32 Yield 0.936

THE WALL STREET JOU

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Home World U.S. Politics Economy **Business** Tech Markets Opinion Life

Kelly Garrett, a farmer near Denison, Iowa, got a $75,000 check in Nov

By Jacob Bunge | Photography by Rachel Mummey for The Wall Street Journal

Dec. 23, 2020 5:30 am ET

RollingStone ≡ Menu *Read Next* The Best Portable Speakers for Your Next Beach Date, Pool Party or Backyard Hang

The U.S. Is About to Go All in on Paying Farmers and Foresters to Trap Carbon

The problem is, it's unclear if "Carbon Offsets" even work

By NATHANAEL JOHNSON & YSABELLE KEMPE

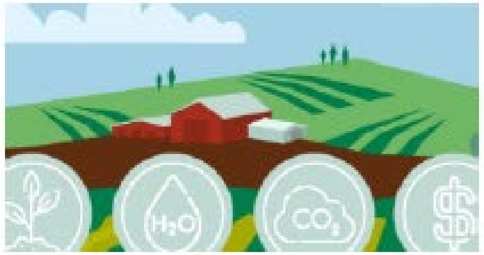
Illustration by Amelia Bates/Grist

Carbon markets agree,
we still need to collect soil samples

ILLINOIS SUSTAINABLE AG PARTNERSHIP

https://ilsustainableag.org

Ecosystem Market Information

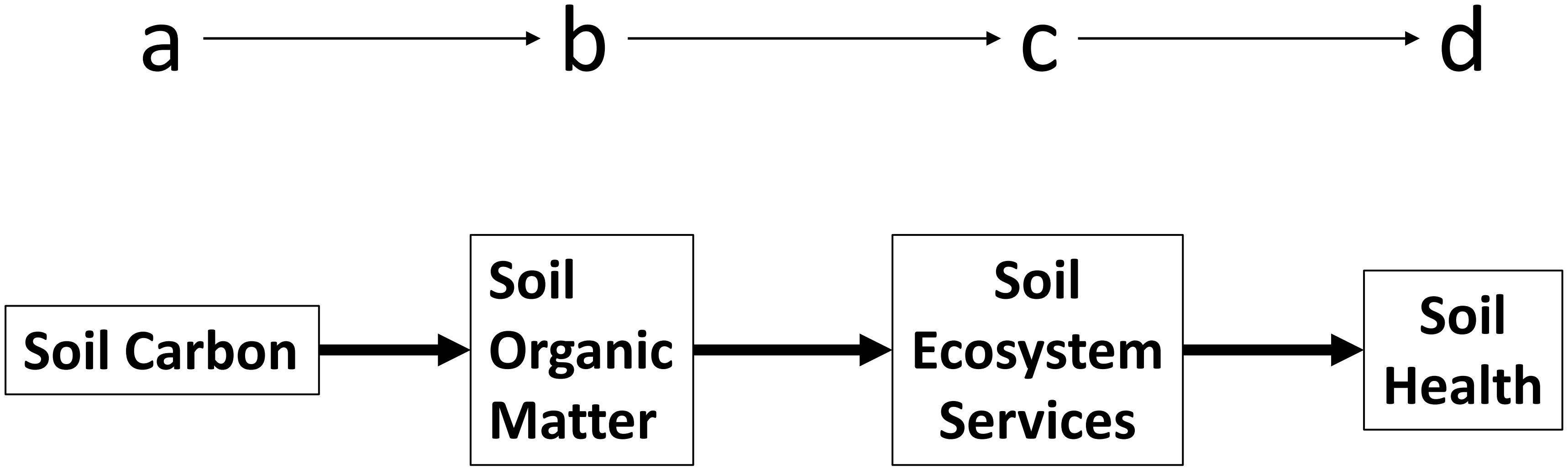


	Nori	Indigo Ag	Soil & Water Outcomes	ESMC
Outcome Estimation	Soil sample reference network-based modeling (Soil Metrics) - cost incurred by Nori. Farmer has option to true-up via soil sampling - farmer incurs sampling cost.	Modeling (biogeochemical and statistical) + soil sampling, Indigo assumes cost (Indigo does not charge growers for anything)	Modeling, with 10% of fields subject to in-field soil and water sampling at no cost to farmer	Modeling (peer reviewed biogeochemical model) + soil sampling. ESMC assumes costs and includes in asset price to buyers.
Third Party Practice Verification	Minimum once every 3 years; standard audit procedure (review representative sample of receipts and invoices)	Random site visits and evidence checks, registry-approved methodology.	Yearly field visits, remote sensing	Scope 1– small subset of producers randomly selected for site visit + remoting sensing. Scope 3 –smaller subset of producers randomly selected for site visit +remote sensing.
Data Collected on Enrollment	Farm operational data – previous 10 years OR proprietary *"Smart Defaults"* option	Basic farmer info, field boundaries, and commitment to new practice(s)	Farm operational data – 2-3 years historical baseline plus 2-3 years of proposed practice change(s)	Scope 1 – detailed farm operational data Scope 3 – some operational data; Soil sampling and remote sensed data for both.

See Dr. Alejandro Plastina's new publication for more info!

February 2021

Transitive Properties of Soil Carbon



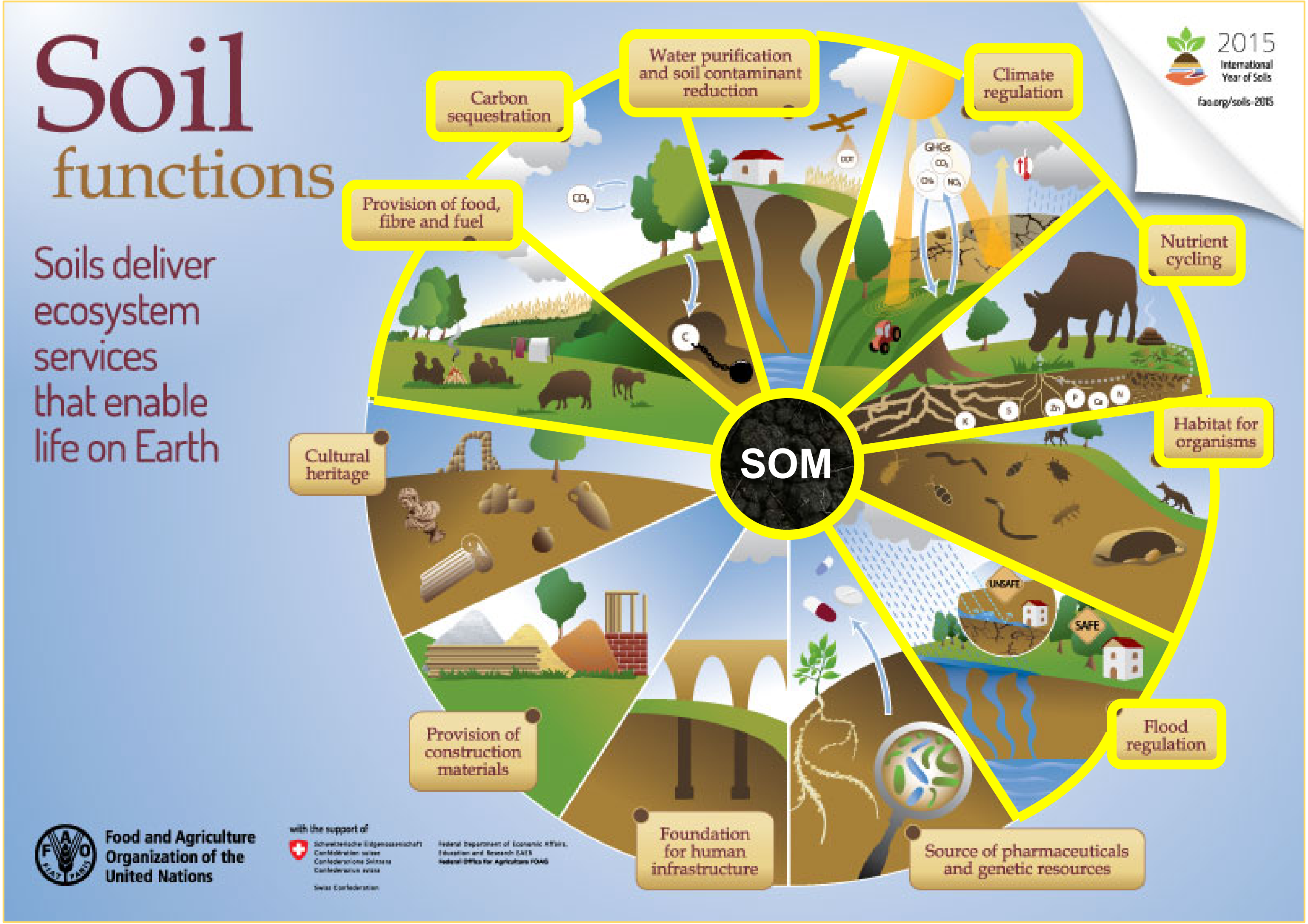
What we want to buy and track with C markets

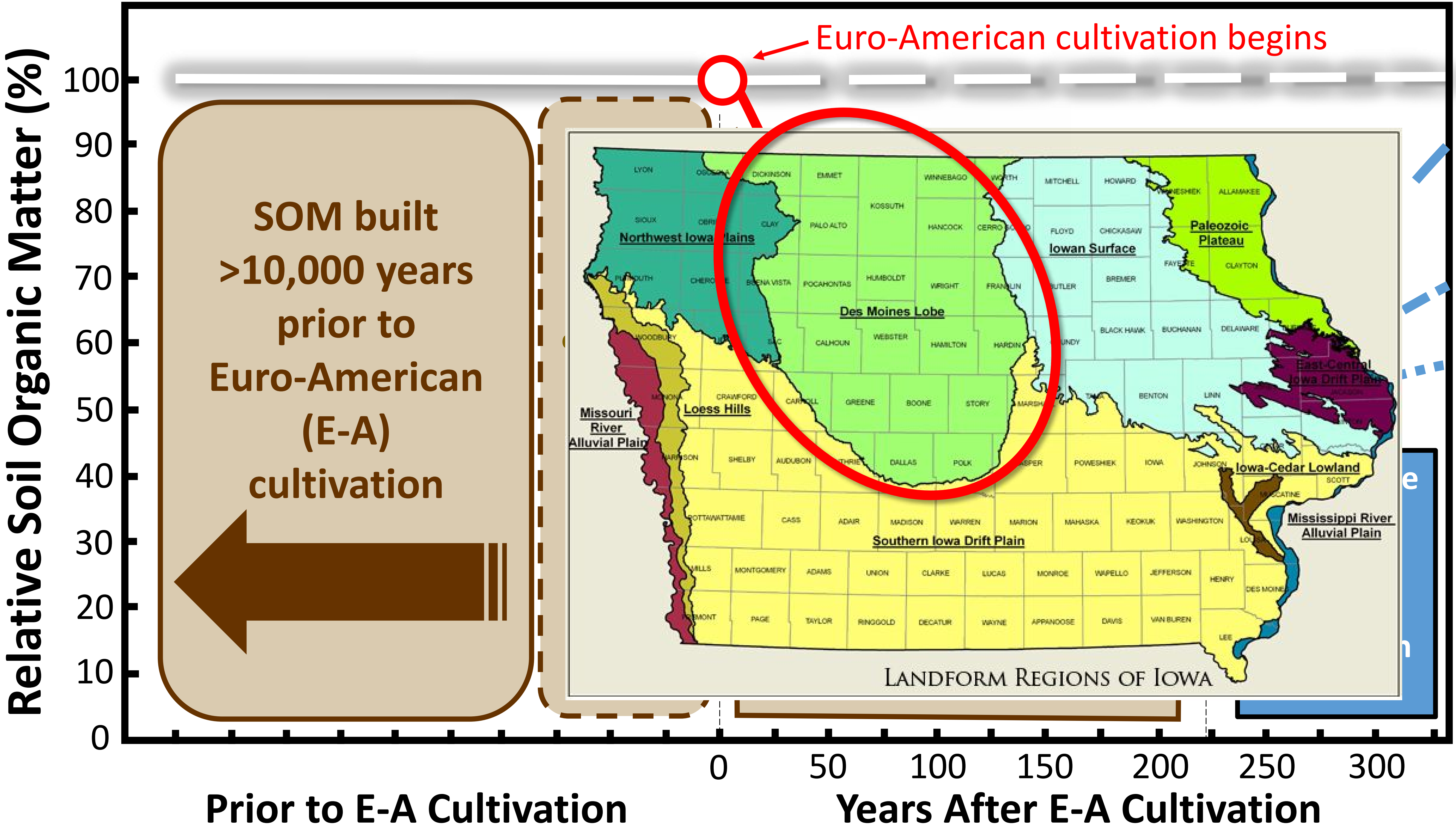
- **<u>Carbon (58%)</u>**
- Hydrogen
- Oxygen
- Nitrogen Phosphorus
- Sulfur

- Water holding capacity
- Soil stability
- Nutrient storage/release
- Climate change mitigation

SOC ≈ SOM

SOM is central to many soil functions we care about as agronomists

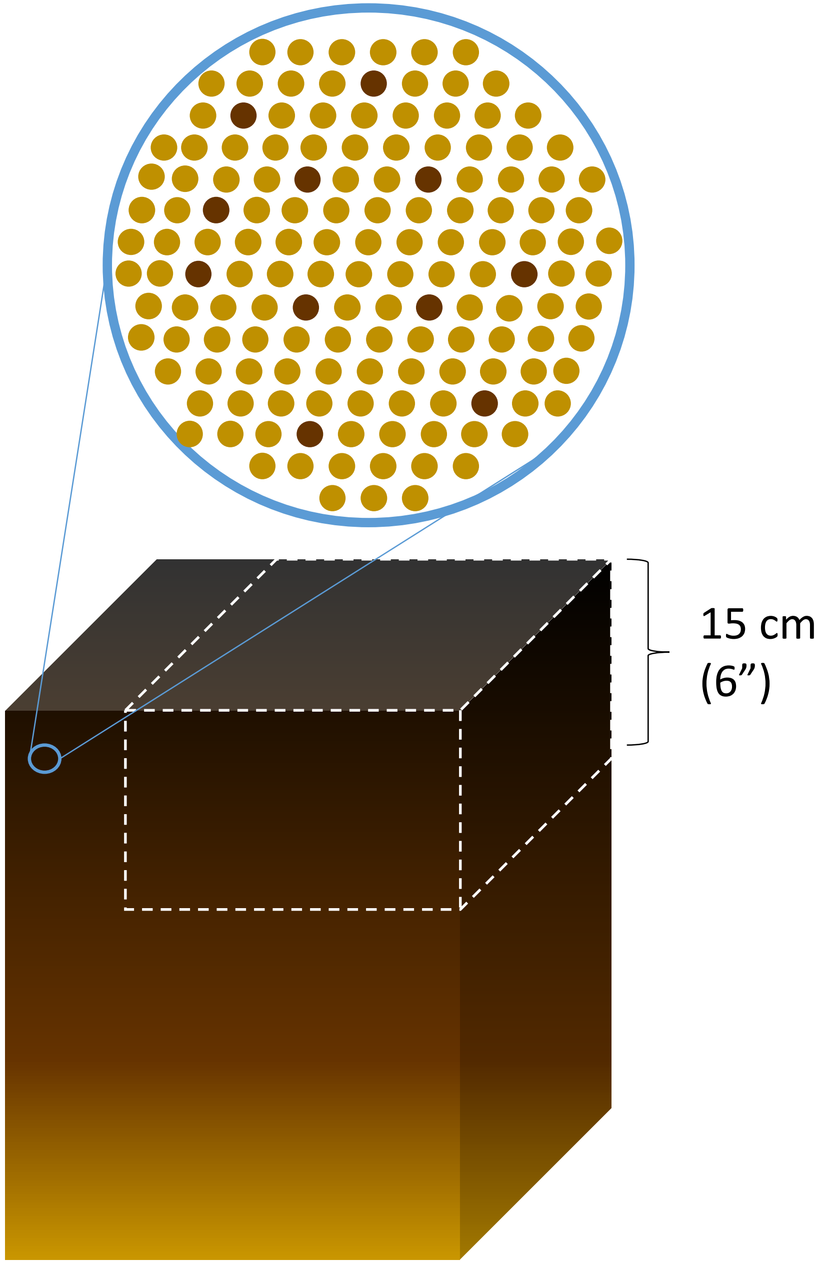



Euro-American cultivation begins
Relative Soil Organic Matter (%)
100
90
80
70
60
50
40
30
20
10
0
SOM built >10,000 years prior to Euro-American (E-A) cultivation
0
50
100
150
200
250
300
Prior to E-A Cultivation
Years After E-A Cultivation
Northwest Iowa Plains
Des Moines Lobe
Iowan Surface
Paleozoic Plateau
East-Central Iowa Drift Plain
Missouri River Alluvial Plain
Loess Hills
Iowa-Cedar Lowland
Mississippi River Alluvial Plain
Southern Iowa Drift Plain
LANDFORM REGIONS OF IOWA

Soil C Jargon

C Stock

Definition	Mass C per unit area (per depth)
Typical Units	Mg/ha
Required to calculate	C concentration, bulk density, depth
Advantages	• Can compare to plant C inputs • Estimate total mass to depth for a field
Disadvantages	• Bulk density onerous and very error-prone to measure • Spatial variability
Typical Values for IA Mollisols*	100 to 250 Mg/ha (1.5 m or ~5’)



*Mann (1985)_Geoderma

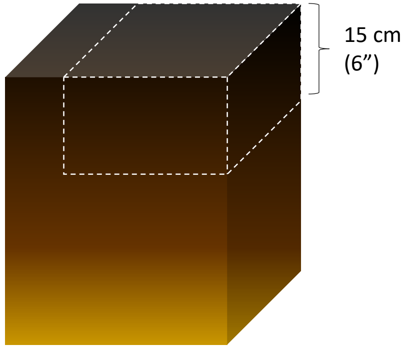
Soil sampling/handling/C-analysis

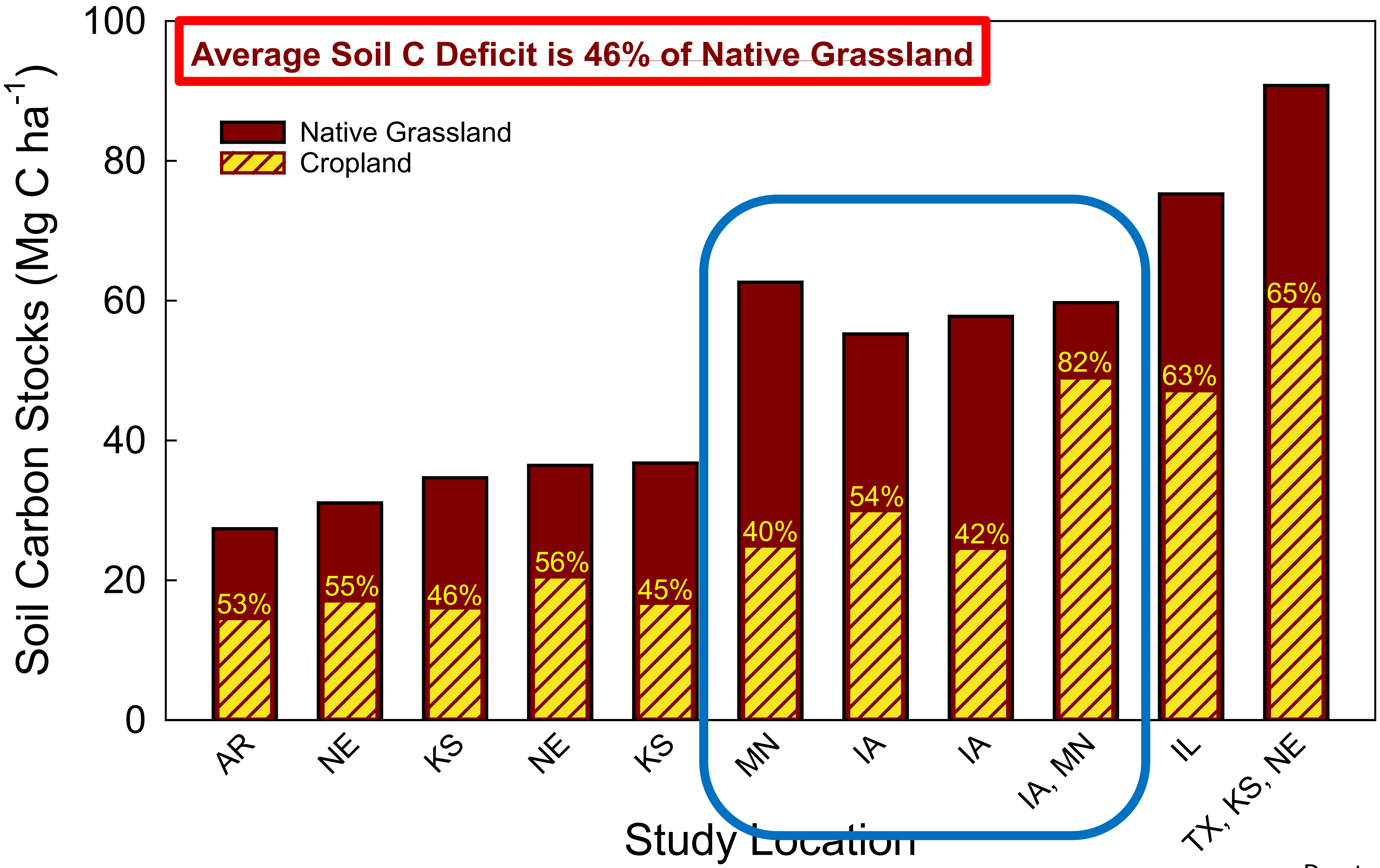
This is how we normally analyze SOM or SOC in a soil sample

Muffle Furnace
(soil organic matter)

Elemental Analyzer
(soil carbon)

We have an ~50% SOC deficit, so we can double SOC (**maybe?!**)





De et al. (2020)_SSSAJ

5 Principles of Soil Health

USDA Natural Resource Conservation Service

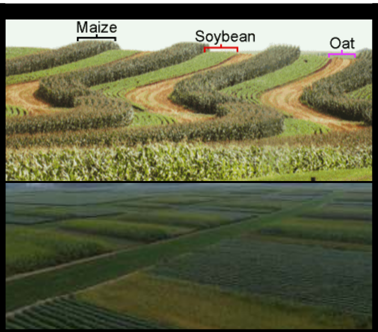
Soil Armor

- Cover crops
- Residue
- Reduced tillage
- CRP or Prairie Strips

Minimize Disturbance

- Reduced tillage
- Lower compaction (controlled traffic)
- CRP or Prairie Strips

Plant Diversity



- Cover crop mixtures
- Crop rotations
- Intercropping
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Continual Live Plant/Root (Perenniality)

- Cover crops
- Perennial crops
- Relay cropping
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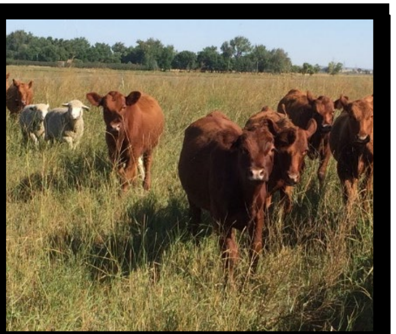
Livestock Integration



- Grazing cover crops
- Seed pastures in rotation
- Adding manure

5 Principles of Soil Health

(USDA Natural Resource Conservation Service)

Soil Armor (SA)	Minimize Disturbance (MD)	Plant Diversity (PD)	Continual Live Plant/Root (CP)	Livestock Integration (LI)

Soil Health Promoting Practice	NRCS Soil Health Principles Covered	SOC Change	SOC Change from Control	Number of Studies	Mean Study Years	Mean Soil Depth	Reference
		Mg C ha⁻¹ y⁻¹ ± standard deviation	*% Δ C y⁻¹ (95% Confidence Interval)*	n	y (range)	cm (range)	
Conservation Tillage	SA, MD	0.63 ± 0.15	4.9 (1.2 to 8.6)	67,267	14 (6 to 100)	22 (7.5 to 30)	West & Post (2002); Bai (2019)
Crop Rotation	PD, SA	0.14 ± 0.06	0.2 (0.1 to 0.3)	122	18 (2 to 98)	21 (5 to 120)	McDaniel (2014)
CRP or Restored Prairie	SA, MD, PD, CP	0.46 ± 0.09	2.0 (1.2 to 2.8)	13	23 (5 to 40)	35 (10 to 300)	De et al. (2019); Also see Guo & Gifford (2002)
Cover Crops	SA, PD, CP	0.35 ± 0.09	6.2 (5.1 to 7.3)	30,32	5	NA	Poeplau & Don (2015); Bai (2019)
Manure*	LI	0.34 ± 0.25	0.7 (0.5 to 0.9)	42	18	26 (15 to 100)	Maillard & Angers (2014)
Biochar*	NA	NA	39.0 (33.2 to 44.8)	56	3	NA	Bai (2019)

*NOTE: These practices are on a sliding scale, in other words, the more you add the more you get. Here means are provided for average of all applied experimental rates (See Fig. 1).

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Reduced Tillage

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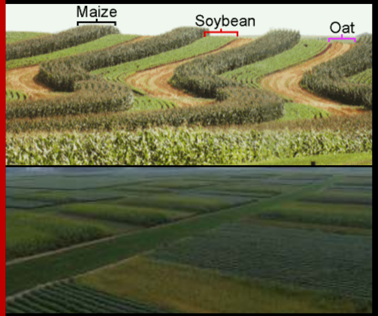
Plant Diversity



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Soil Science Society of America Journal

SOIL & WATER MANAGEMENT & CONSERVATION

Quantifying soil carbon change in a long-term tillage and crop rotation study across Iowa landscapes

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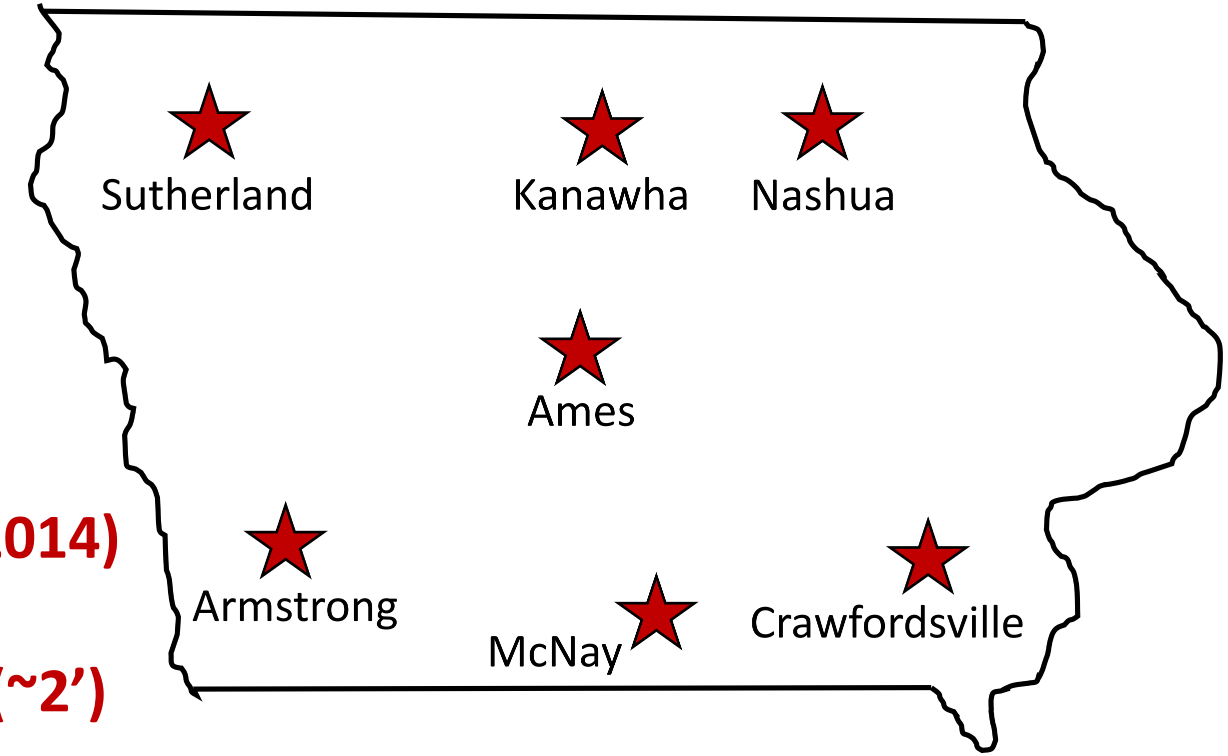
Funding information
College of Agriculture and Life Sciences

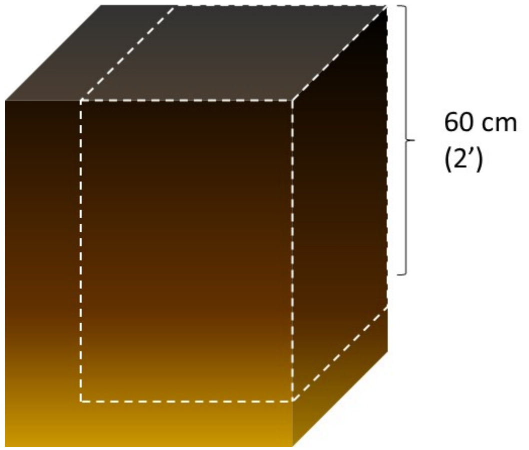
- 12 Years (2002 to 2014)
- C-S, C-C-S rotation
- Sampled to 60 cm (~2')

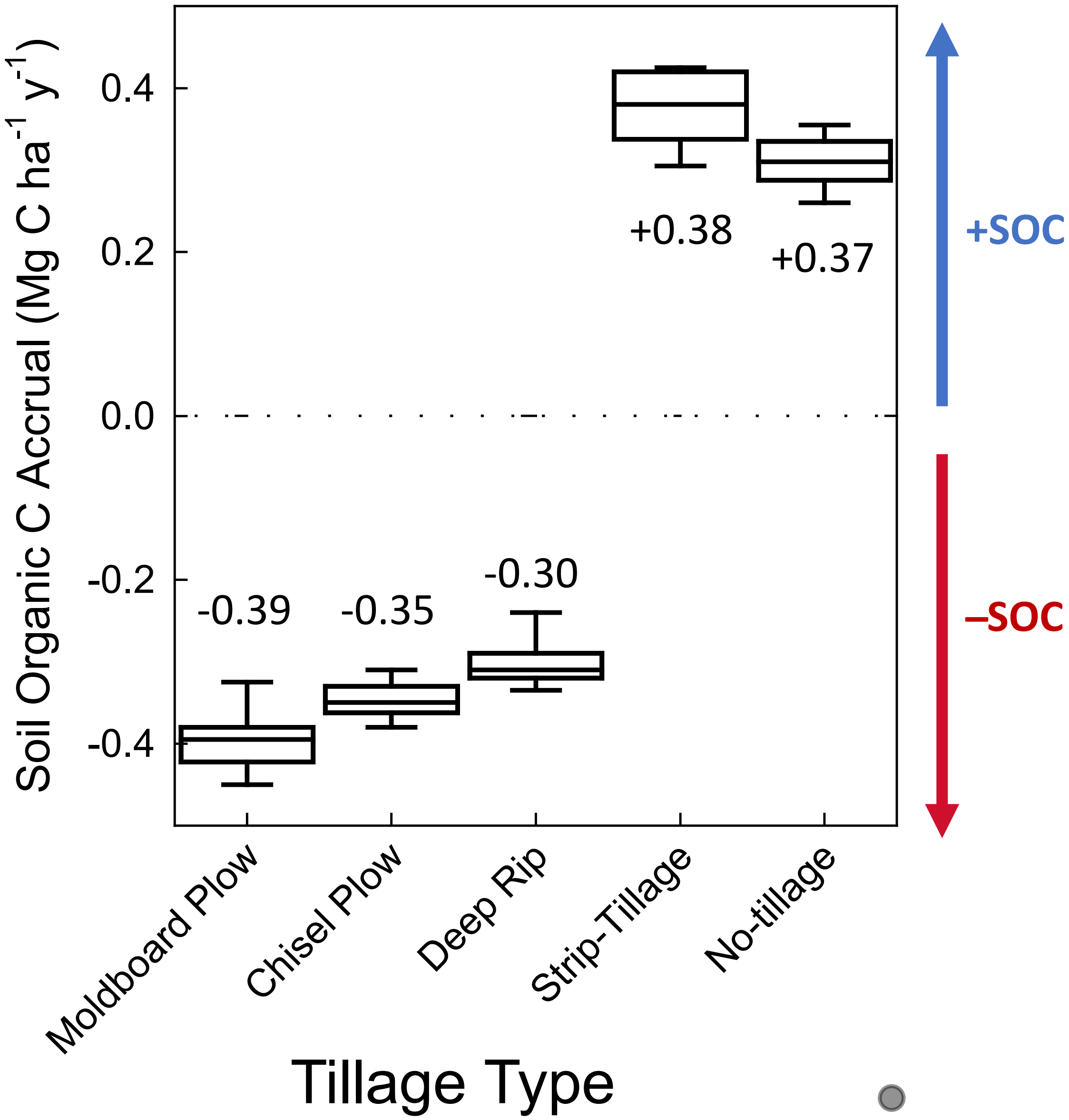


Al-Kaisi & Kwaw-Mensah 2020_SSSAJ

Tillage effects across IA

- MP, CP, DR all decrease SOC (-0.39 to -0.30 Mg C ha^{-1} y^{-1})
- ST and NT increase SOC (+37 to +0.39 Mg C ha^{-1} y^{-1})
- Global increase with NT is 0.63 Mg C ha^{-1} y^{-1}

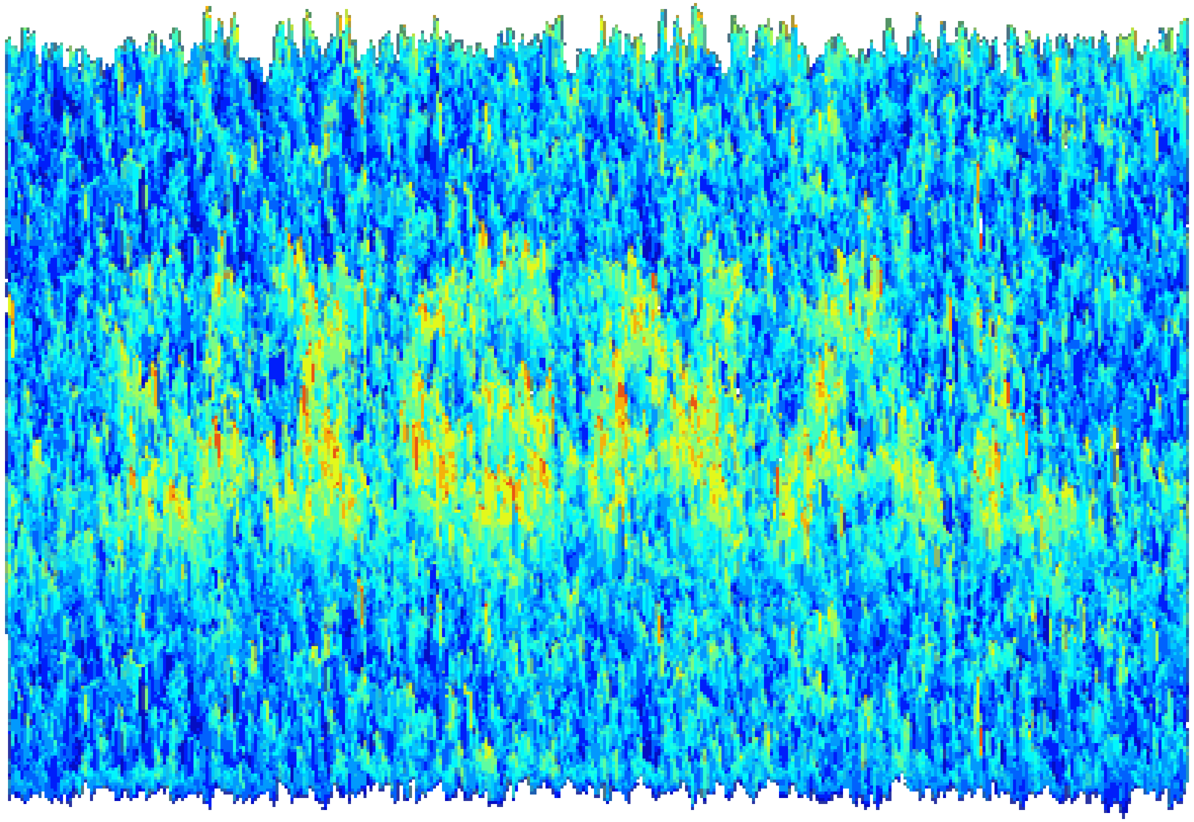




Al-Kaisi & Kwaw-Mensah 2020_SSSAJ

Known Unknowns

- Monitoring SOC change is challenging
  - ✓ Natural spatial variability
  - ✓ Need baseline (original measurements)
  - ✓ Soil depth
  - ✓ Bulk density
  - ✓ Soil sampling/handling/C-analysis
  - ✓ Slow change
  - ✓ Statistical traditions can hinder us
- Co-benefits of increasing SOC
  - Water storage
  - Soil stability
  - Nutrient storage and delivery to plants
- Tradeoffs with increasing SOC
  - Esp. Greenhouse gases and crop yield



Which soil is from an 11-y restored prairie?

(the other has been in corn-soy for >century)

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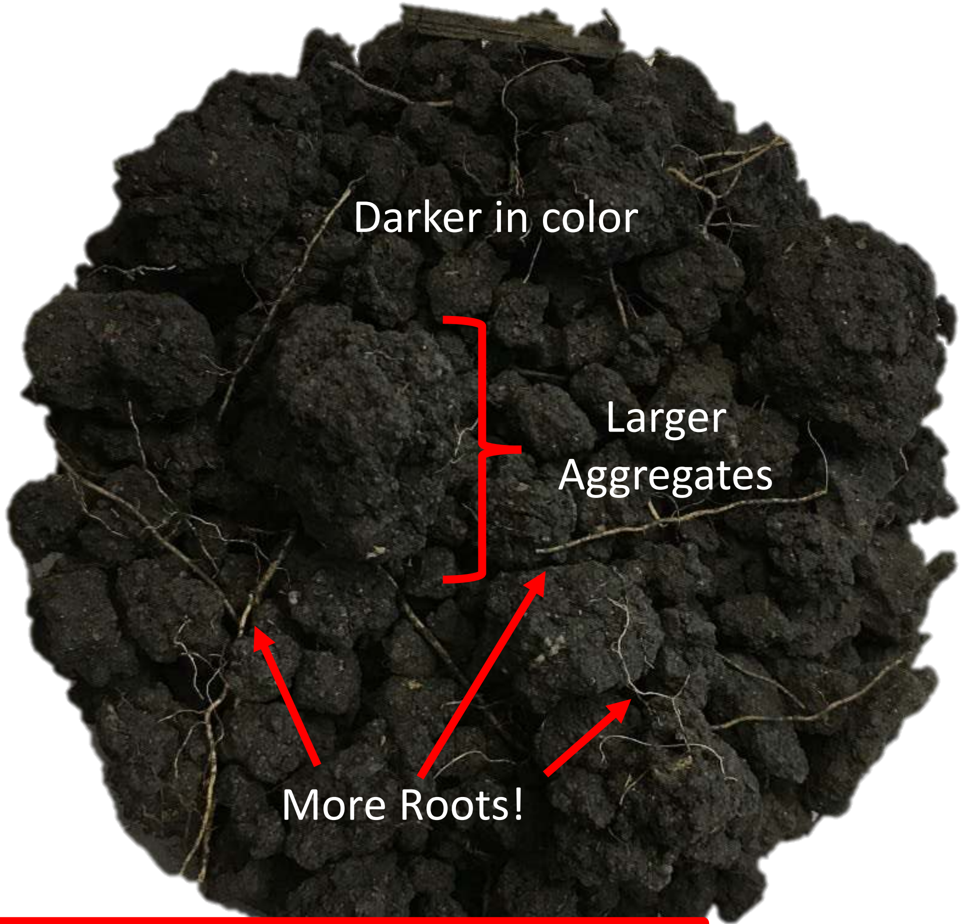
(the other has been in corn-soy for >century)



“No difference in soil C [as measured by EA]” – Dietzel et al. (2017)
Same found by Ibrahim et al. (2018), Ye & Hall (2020) and Middleton et al. (2021)

2.6 % C

3.0 % C

Conclusions

- Q: Do we know enough about soil management and SOC changes to inform C markets?
  - A: ***Yes***, with cautious optimism
- Q: Where should science focus to improve management recommendations and C markets?
  - A:
    1. Invest in long-term experiments – few and far between
    2. Do we need to sample deep?
    3. Explore tradeoffs with other greenhouse gas emissions
    4. Develop inexpensive, accessible ways to measure SOC change

Dick Sloan's farm (near Rowley, IA)

Questions?

Email: marsh@iastate.edu
@Soil_Plant_IXNS on Twitter

Photo: Omar de Kok-Mercado

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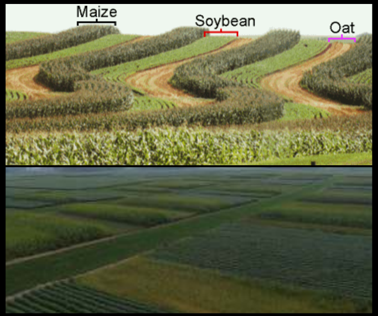

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Manure

Livestock Integration

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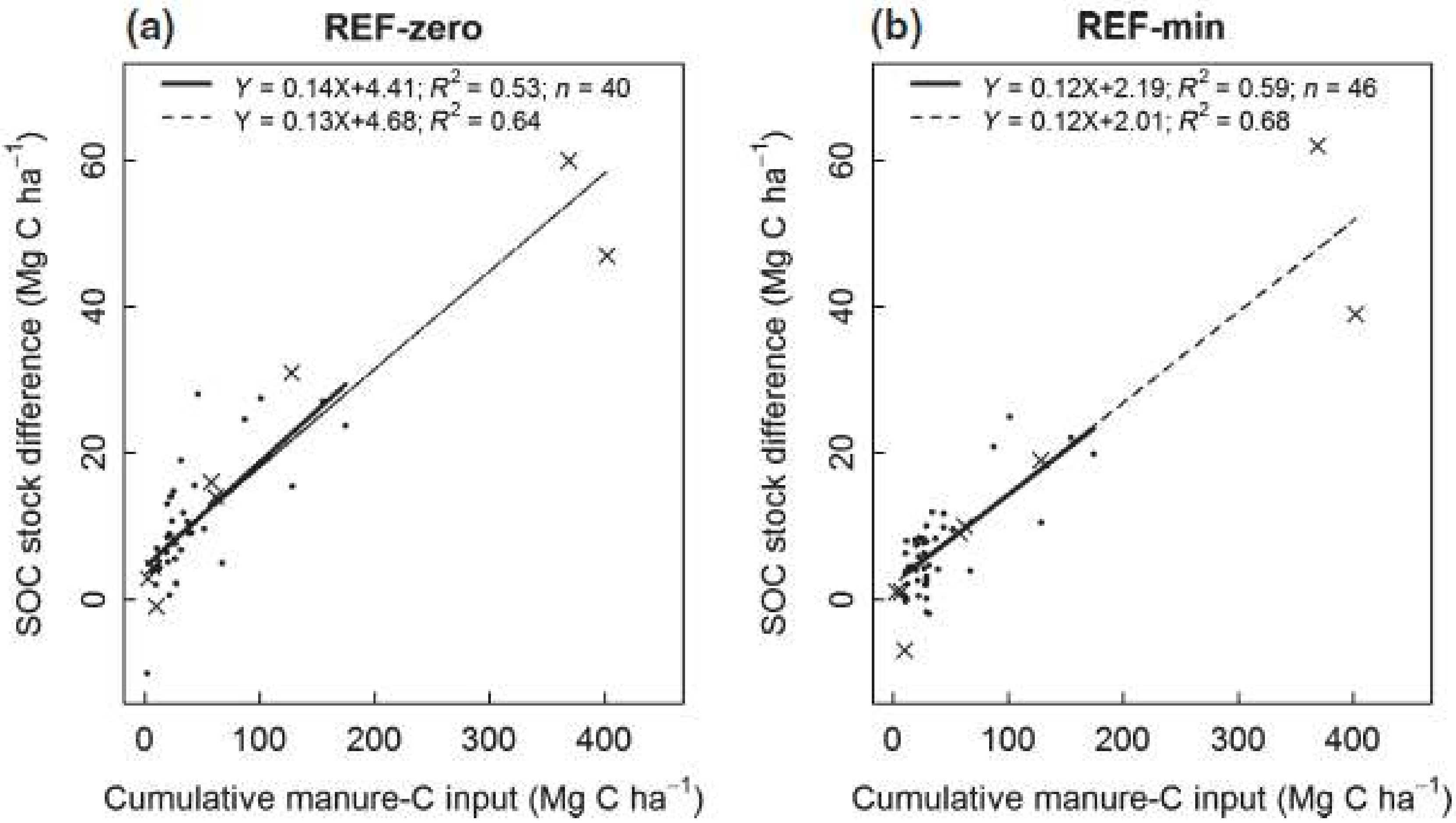
Manure – a sliding scale, the more you add the more you get



12-14% of manure C becomes long-term, persistent soil organic C

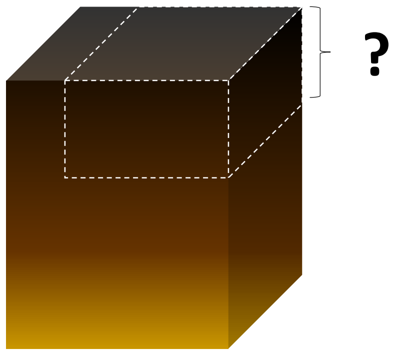


*Figure from **Maillard & Angers (2014)** showing increasing manure C added regressed with corresponding difference in soil organic C between control with no fertilizer (left) and equivalent inorganic fertilized (right). Dots (●) represent replicated sites and × represent non-replicated.*

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This just in!!!

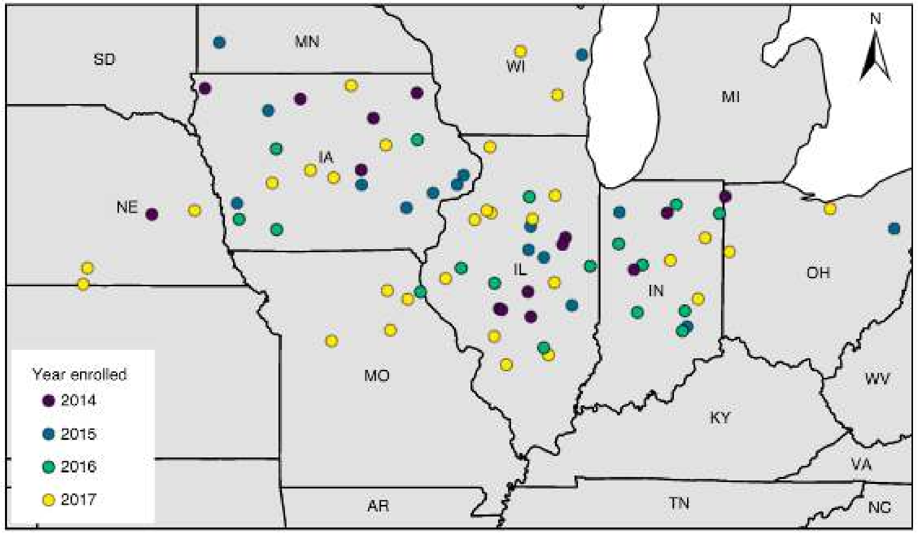
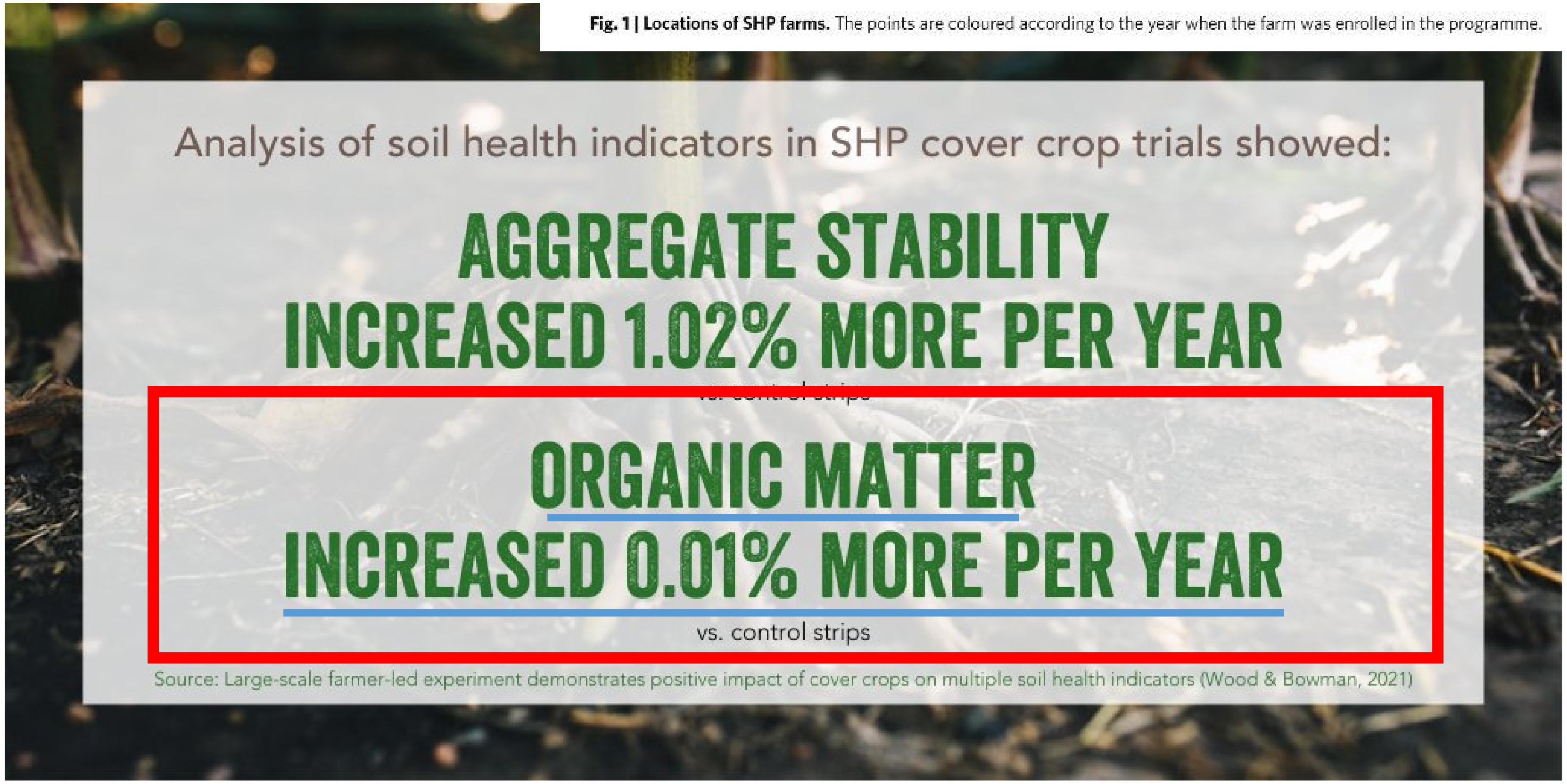


Fig. 1 | Locations of SHP farms. The points are coloured according to the year when the farm was enrolled in the programme.



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CRP or Prairie Strips

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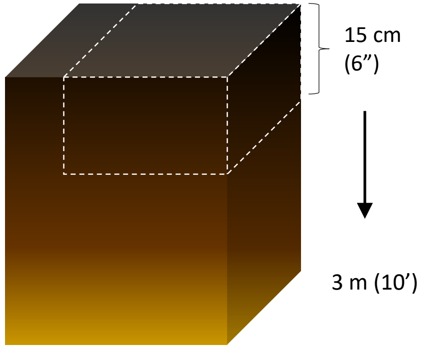
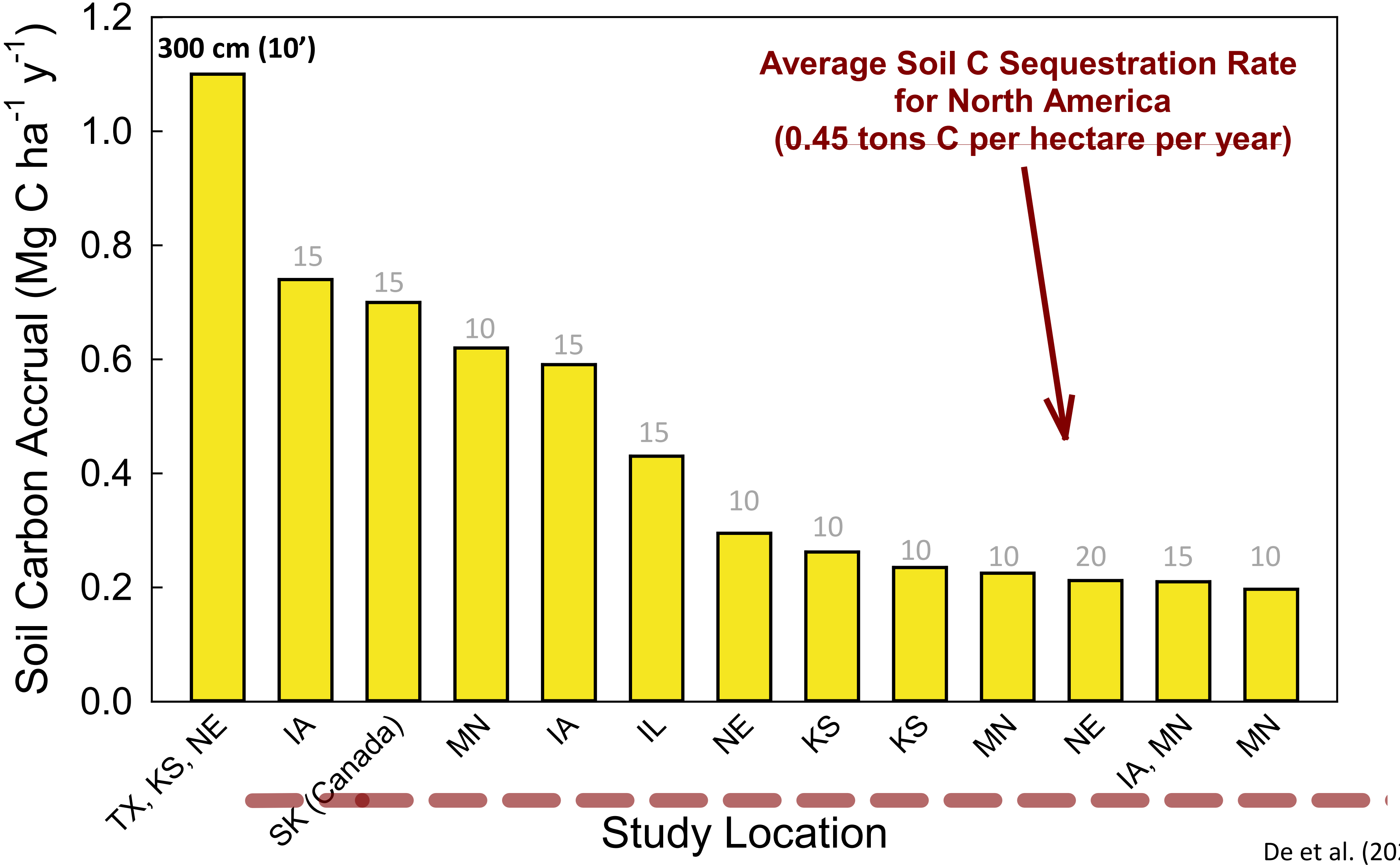
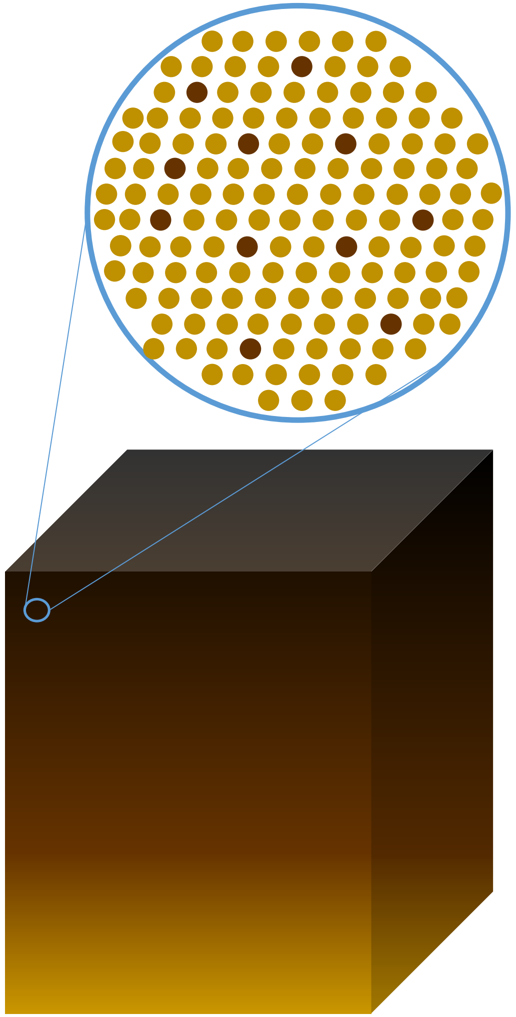
Depth/soil matters, but CRP increases SOC 0.45 tons C ha^{-1} y^{-1} (or 1-2% in concentration per year from cropland)



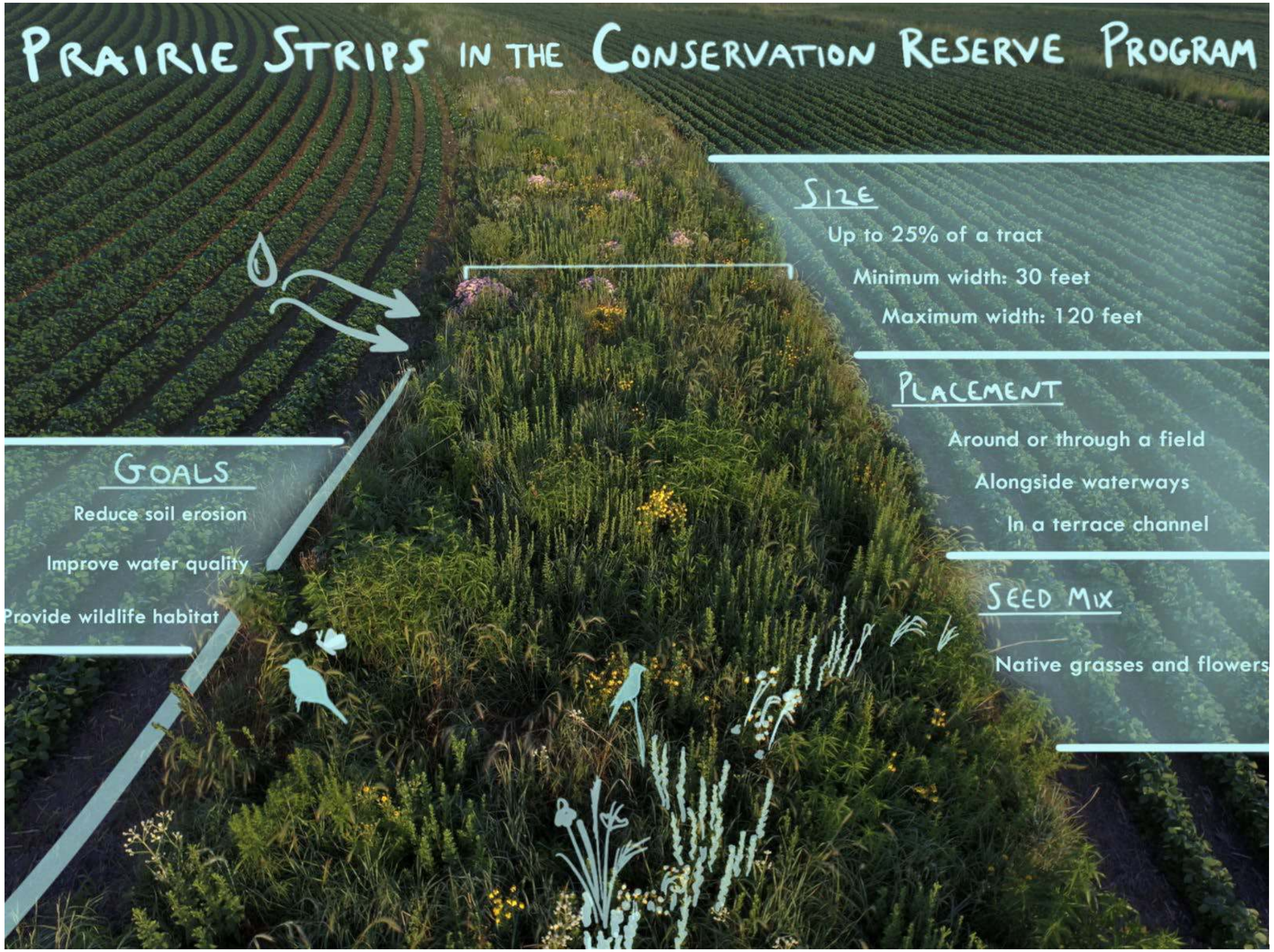


De et al. (2020)_SSSAJ

SOIL C under Prairie Strips



Science-based Trials of Rowcrops Integrated with Prairie Strips



STRIPS

14 states

11,735 acres of prairie strips

112,707 cropland acres protected

Why prairie?

- ✓ Perennial cover
- ✓ Deep roots
- ✓ Stiff, erect stems
- ✓ Diverse
- ✓ Native

Photograph by Jim Richardson

Photo: Sarah Hirsh

Source: Asbjornsen et al. 2014

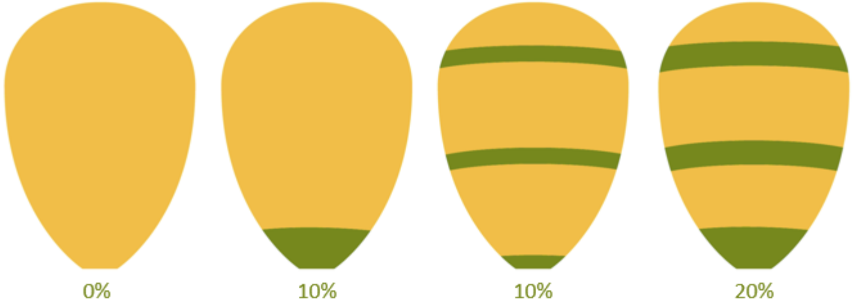
Prairie Strips = Disproportional Benefits

Photo:
Omar
de Kok-
Mercado

Highlights from the 1st Decade of STRIPS Research

Experimental Treatments

12 catchments; 0.5–3.2 hectares; 6-11% slope
Randomized Incomplete Block Design:
3 reps X 4 treatments X 3 blocks



= no-till corn and soybean ***row crops***
= reconstructed ***prairie***

Strategically adding 10% prairie to no-till corn-soy fields:

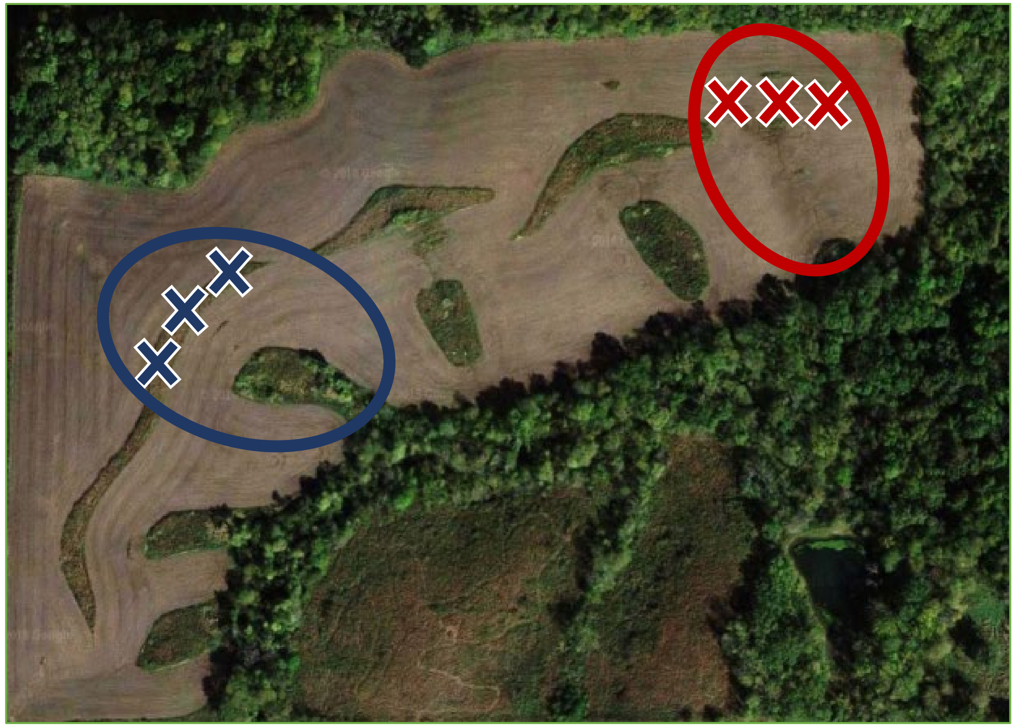
- ✓ 37% reduction in water runoff
- ✓ 95% reduction in sediment loss
- ✓ 77% reduction in phosphorus runoff
- ✓ 70% reduction in nitrogen runoff
- ✓ 70% reduction in subsurface NO_3-N concentrations (not tiled)
- ✓ More than triple pollinator and double bird abundance
- ✓ Influence on crop yield proportionate to non-cropped area
- ✓ No additional weed problems
- ✓ Cheaper than installing terraces; cost comparable to cover crops

What about soils under and around prairie strips?

Source: Schulte et al. 2017 PNAS

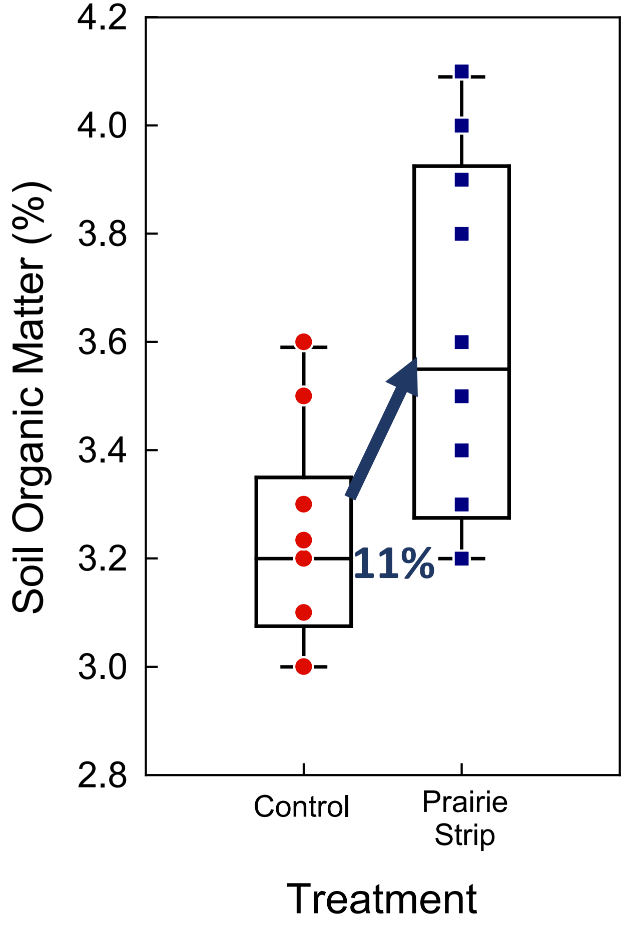
Do prairie strips follow this "1% per year" rule?

Neal Smith National Wildlife Refuge
(Prairie City, IA)



Sampled 12 Years After Establishment

0.03% SOM y^{-1} Increase

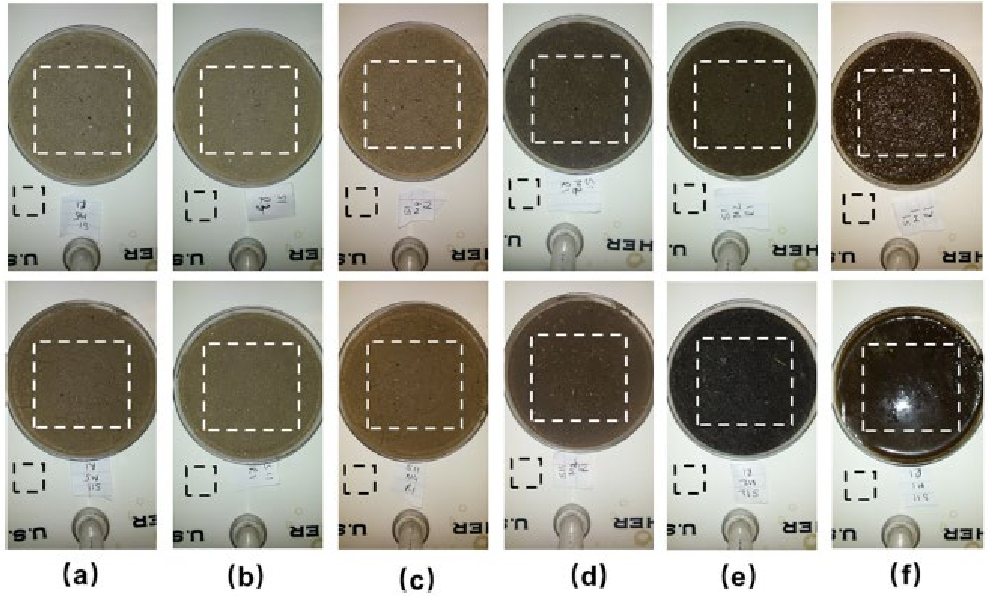


Unknown Unknowns

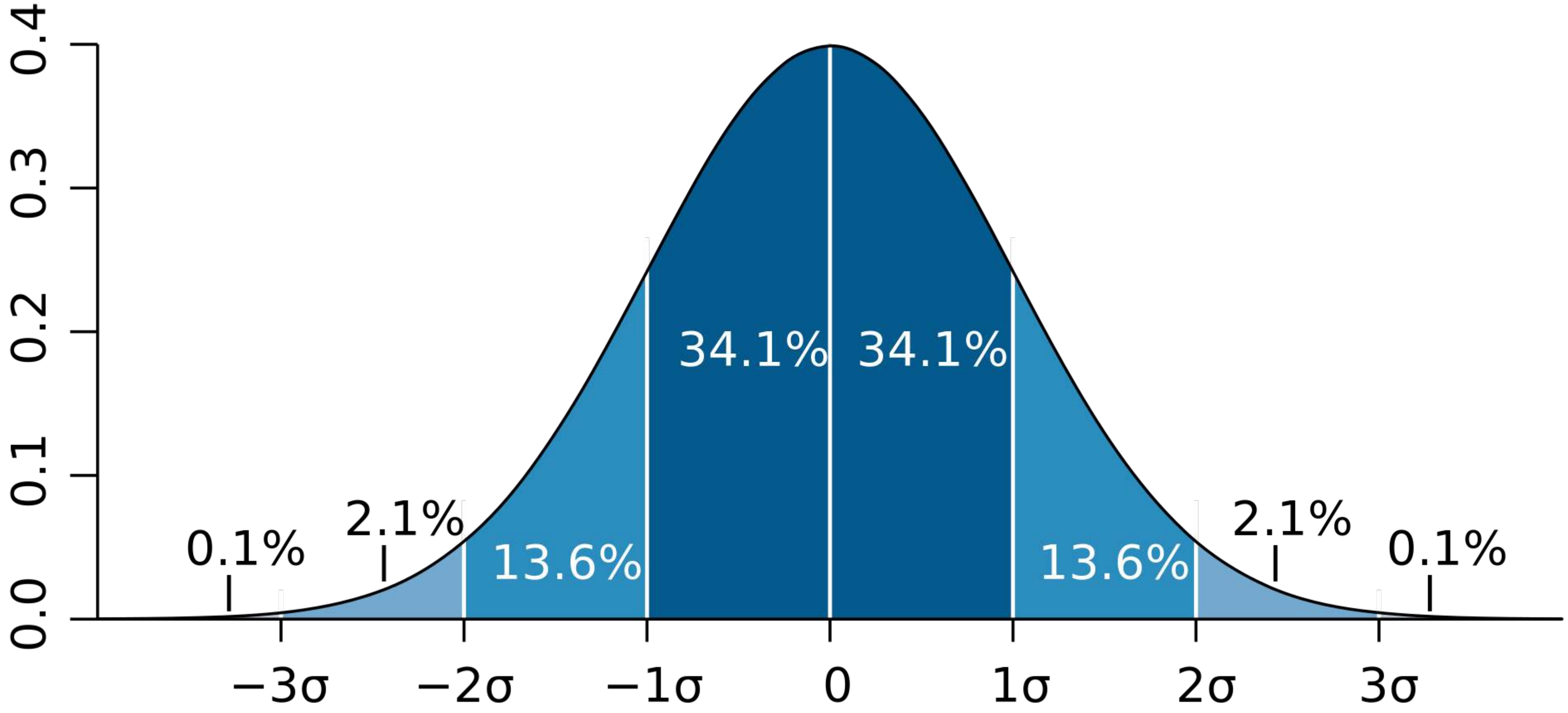
- Government involvement
  - C market and standardization
- How good are our soil C models
- Technology needs to change the way we monitor SOC change
  - Needs to be fast, inexpensive and easily applied across a landscape (probably not sampling soil deep)

nix™ Color Sensor

https://www.nixsensor.com/blog/using-nix-pro-soil-color-sensor-data/



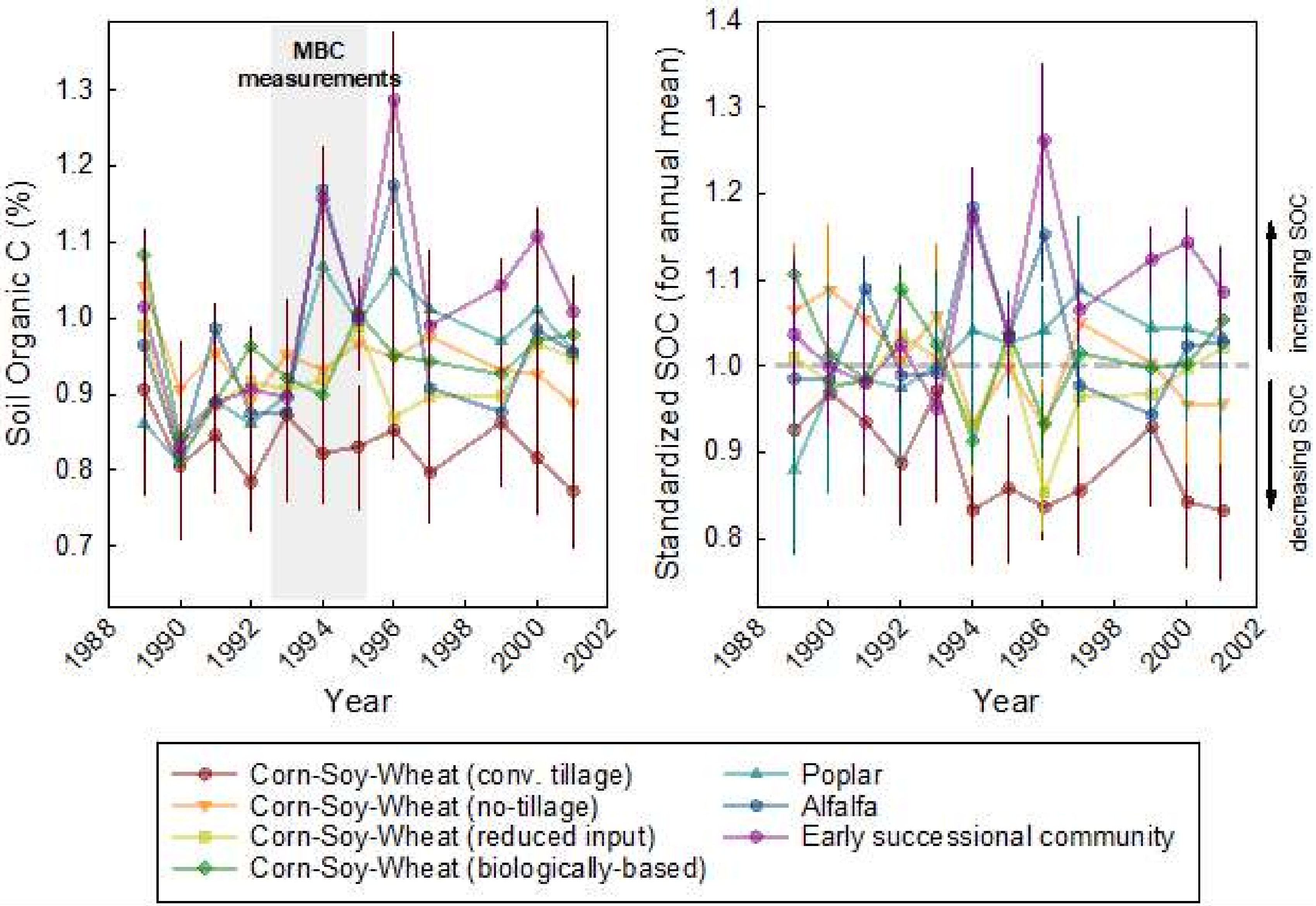
Fu et al. (2020)_Geoderma


0.4
0.3
0.2
0.1
0.0
34.1%
34.1%
13.6%
13.6%
2.1%
2.1%
0.1%
0.1%
−3σ
−2σ
−1σ
0
1σ
2σ
3σ

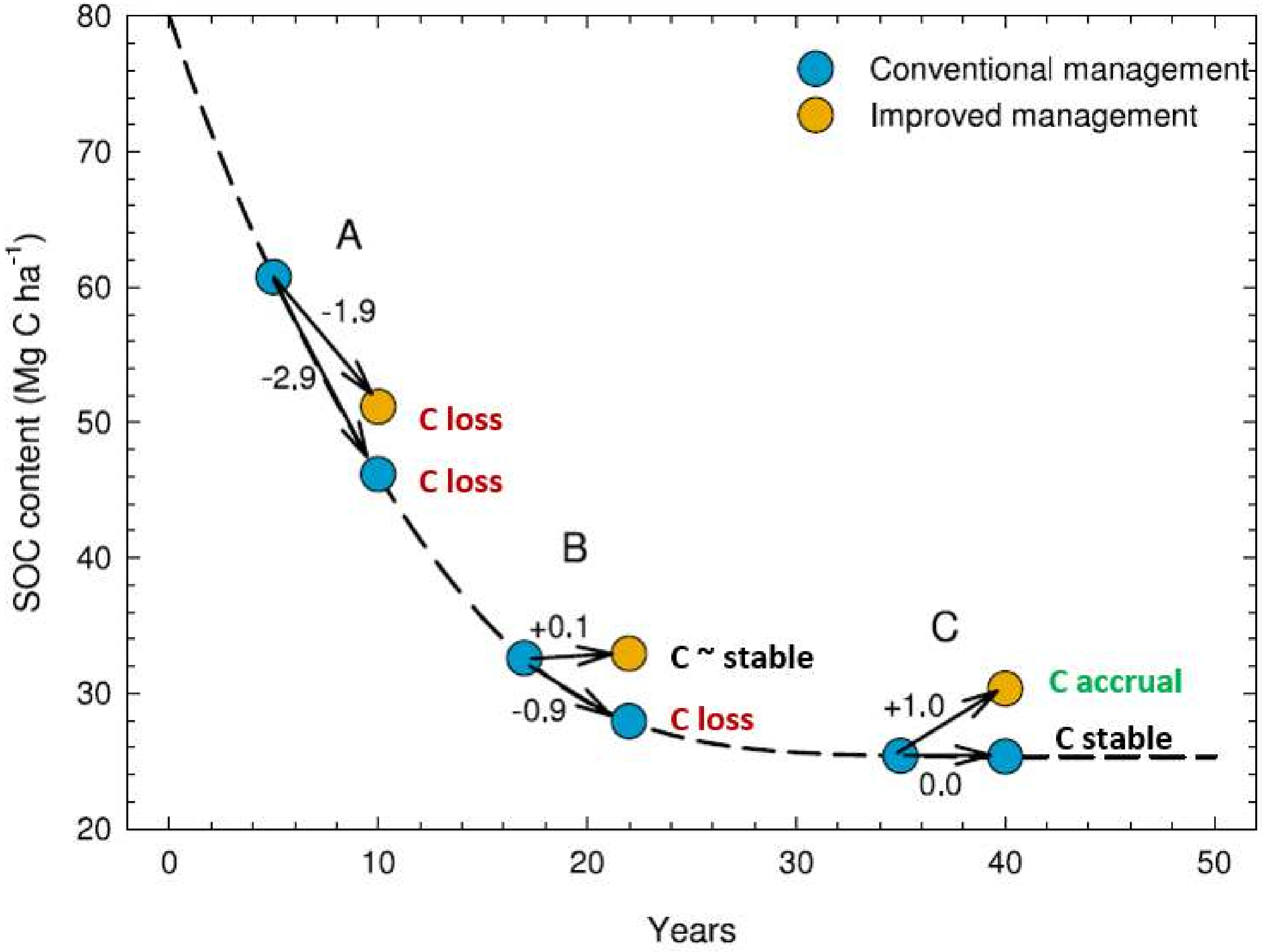
Challenges with measuring changes in quantity of SOM (or SOC)

1. Natural variability
2. Baseline or original measurements
3. Soil depth
4. Bulk density
5. Soil sampling/handling/C-analysis
6. Slow change

1. Natural Variability



2. Baseline or original measurements



Sanderman & Baldock (2010)_Env. Res. Letters

3. Soil depth

Available online at www.sciencedirect.com

ScienceDirect

Agriculture, Ecosystems and Environment 118 (2007) 1–5

ELSEVIER

Agriculture Ecosystems & Environment

www.elsevier.com/locate/agee

Tillage and soil carb

John M. Baker [a,b]

[a] USDA-ARS, 454

[b] Department of Soil, Water & Climate, Un

Received 1 Februar

Received: 16 August 2019 | Accepted: 24 September 2019

DOI: 10.1111/gcbb.12657

ORIGINAL RESEARCH

Mechanisms underlying and cover-cropped bioer

Chenglong Ye[1,2] | Steven J. Hall[1]

Global Change Biology

PRIMARY RESEARCH ARTICLE | Full Access

Deep soil inventories reveal that impacts of cover crops and compost on soil carbon sequestration differ in surface and subsurface soils

Nicole E. Tautges, Jessica L. Chiartas, Amélie C. M. Gaudin, Anthony T. O'Geen, Israel Herrera, Kate M. Scow

First published: 13 July 2019 | https://doi.org/10.1111/gcb.14762 | Citations: 15

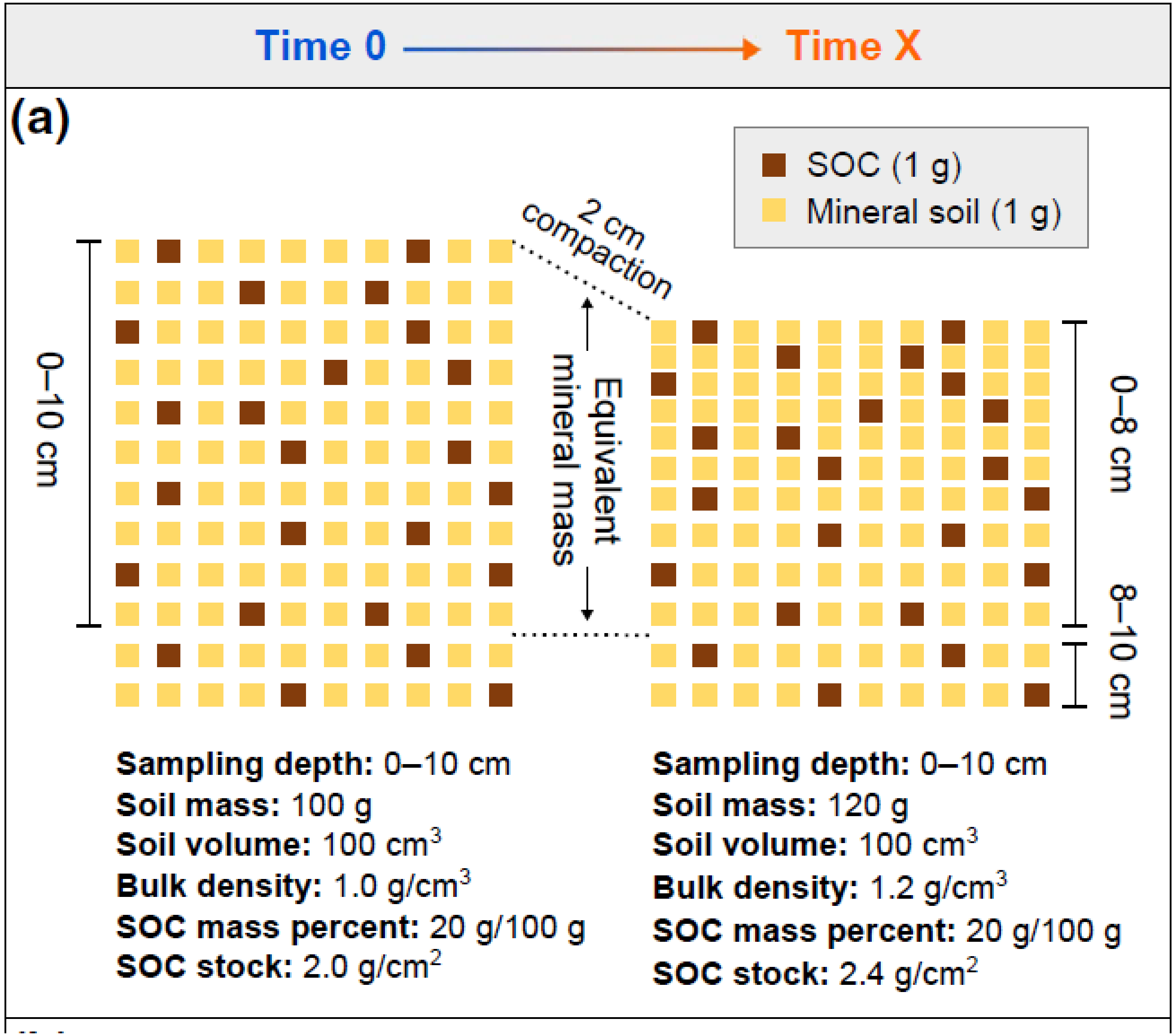
Tautges and Chiartas share joint first authorship.

SECTIONS PDF TOOLS SHARE

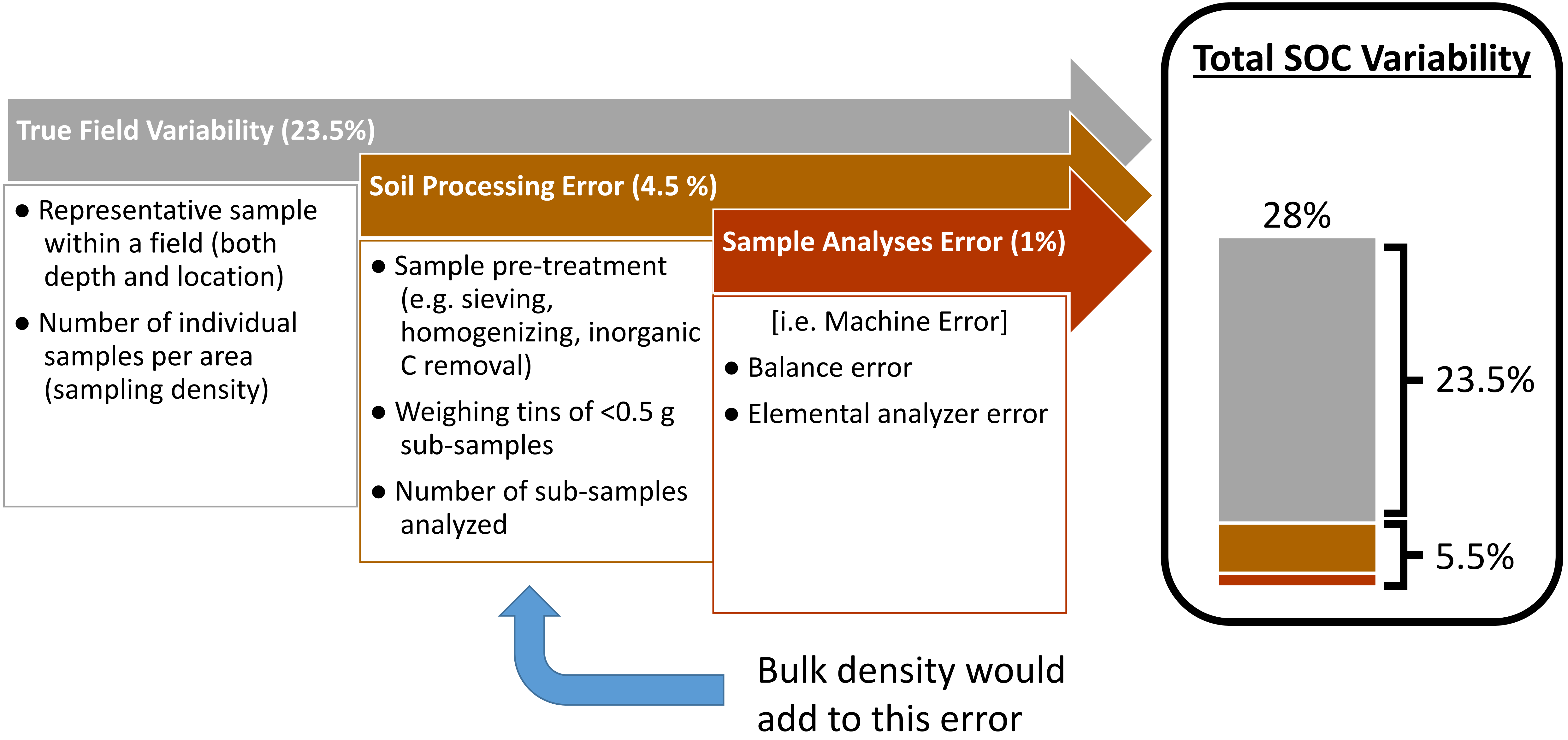
"However, sampling protocol may have biased the results. In essentially all cases where conservation tillage was found to sequester C, **soils were only sampled to a depth of 30 cm or less, even though crop roots often extend much deeper**"

4. Bulk density

- Needed for any C stock estimate or change in stock (Mg C ha^{-1}, Mg C ha^{-1} y^{-1})
- It is very dynamic within year!
- It is also not easy to measure
    - wide cores (> 1-2”) for good estimate
    - lots of error



Von Haden (2020)_GCB


True Field Variability (23.5%)
Soil Processing Error (4.5 %)
Sample Analyses Error (1%)
Total SOC Variability
● Representative sample within a field (both depth and location)
● Number of individual samples per area (sampling density)
● Sample pre-treatment (e.g. sieving, homogenizing, inorganic C removal)
● Weighing tins of <0.5 g sub-samples
● Number of sub-samples analyzed
[i.e. Machine Error]
● Balance error
● Elemental analyzer error
28%
23.5%
5.5%
Bulk density would add to this error

6. Slow to change